WIRELESS TRANSMISSION OF ENERGY.[1]

By Elihu Thomson.

It will be my purpose in the present discourse to outline the general nature of wireless transmission and to indicate its relationship to transmission by wire. It will also be my object to show why the wireless energy sent out follows the curvature of the earth and to explain other features which to many have been more or less puzzling. In short, I desire to present in simple terms a view of the nature of such wireless work, so that anyone reasonably informed about electrical actions can obtain, as it were, a mental picture of the process. I may here state the fact that perhaps one of the earliest experiments bearing on wireless transmission was made in company with Prof. E. J. Houston, while we were both teachers in the Central High School in Philadelphia. This old experiment to which I refer was made about the latter part of 1875, and briefly described in the Franklin Institute Journal early in 1876. It consisted in using an induction coil which would give a spark length of several inches, then known as a Ruhmkorff coil, the coil resting on the lecture table, one terminal of the fine wire or secondary of which was connected to a water-pipe ground, while the other was connected by a wire 4 or 5 feet long to a large tin vessel supported on a tall glass jar, insulating the tin vessel from the lecture table. The coil had an automatic interrupter for the primary circuit, and when in operation the terminals of the secondary were approached so that a torrent of white sparks bridged the interval between them, the gap being about 2 inches or so in length. Figure 1 shows this arrangement. When the coil was worked in this way, it was found that a finely sharpened lead pencil approached to incipient contact with any metallic object—such as door knobs within the room and outside thereof—would cause a tiny spark to appear at the incipient contact between the pencil point and the metal. This, of course, was not a very delicate detector, but was improved, as in figure 2, by putting two sharpened points in a dark box, a device due to

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Edison. One or both points were adjusted so as to make incipient contact, and the tiny spark observed between the points was an indication of a shock, commotion or wave, electrical in its character, in the ether surrounding the tin vessel mounted on the glass jar. The tests for detecting the impulses were carried on not only in rooms on the same floor, but on the floor above and on the floor above that, and finally at the top of the building, some 90 feet away, in the astronomical observatory. Metallic pieces, even unconnected to the ground, would yield tiny sparks, not only in the basement of the building, but in the highest part, with several floors and walls intervening. I mention this old experiment particularly because it has in it the elements, of course in a very crude form, of wireless transmission, the wire and tin vessel attached to one terminal of the coil being a crude antenna with its spark-gap connection to ground, as afterwards used in wireless work by Marconi, and it also shows a rudimentary receiver or detector, a metallic body arranged in connection with a tiny spark gap, so that electrical oscillations in such body would declare themselves by a faint spark at the gap. It was understood by us at the time that after each discharge of the coil there was, as it were, a shock, or wave in the ether consisting of a quick reversed electrical condition, and it was even imagined that there might be in this process the germ of a system of signaling through space. This old work was almost forgotten when it was recalled by the later work of Hertz, about 1887, who demonstrated by suitable electrical apparatus that waves of the general nature of light or heat could be generated, which waves are transmitted with the velocity of light, 186,000 miles per second, and that by suitable resonators or detectors these waves could be made to declare themselves by tiny sparks. The Hertzian oscillator was, as it were, an electrical tuning fork, having an actual rate of vibration peculiar to itself and dependent on its form and dimensions. It was fed with energy from an induction coil and across its spark gap an oscillating discharge took place, which, at each impulse, died out like the discharge of a condenser, but during this discharge it electrically

Fig. 1.

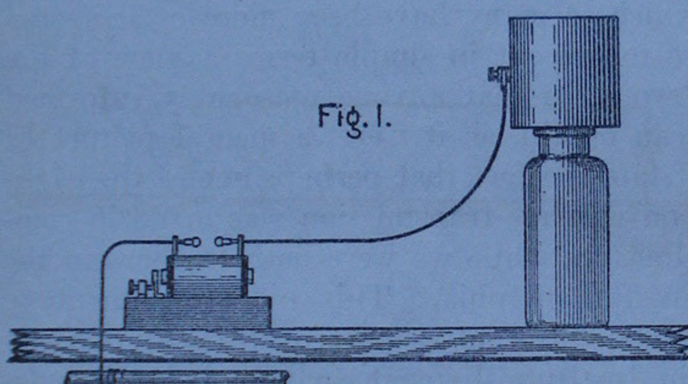
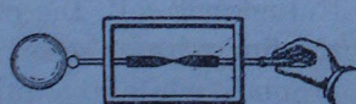


Fig. 2.



stressed the ether in one and the other sense, so that an electrical wave was radiated in certain directions from the oscillator. It was found that these waves could be refracted, reflected, and polarized, and, in general, dealt with as extremely coarse light or heat waves. We shall refer to these, however, farther on. The general result, however, of the Hertzian experiments was to connect electrical waves in the ether surrounding the apparatus with the light and heat waves and prove the identity of the two kinds of radiation, the differences being only those of wave length or pitch.

Since the Hertzian waves were sent out from the Hertzian oscillator in substantially straight lines, and since in the early days of wireless telegraphy it was common to regard wireless waves as of the same nature or as almost identical with Hertzian waves, the fact that the wireless waves were found to follow the curvature of the earth became a difficulty to be explained. Speaking for myself, I have never found the difficulty to exist. There is really no reason why the waves should not follow the curvature of the earth, as it will be one of my purposes to show. We will, however, approach the conditions of wireless somewhat gradually.

Fig. 3.

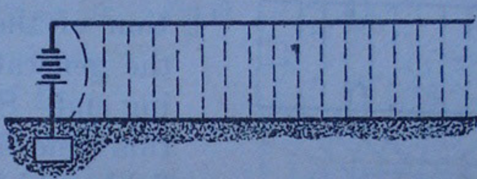


Fig. 4

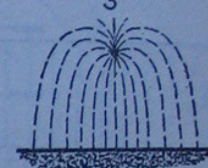


Fig. 5.

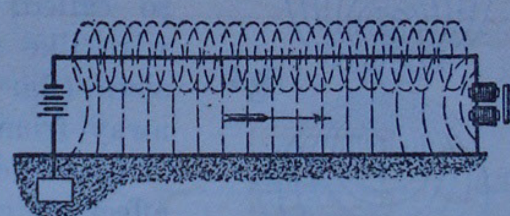


Fig. 6.

We will first consider an ordinary wire transmission of the simplest type. Let us assume a line of wire, as in figure 3, insulated and connected to one terminal of the battery while the other terminal is earthed or grounded. A simple telegraph system on open circuit would represent this arrangement. The only effect is that the battery supplies a small charge to the line, producing a potential difference between the insulated line and the earth, assuming, of course, that there is no leakage of any kind to disturb the conditions. As soon as the charge is established in the line at the full potential of the battery, which, in ordinary cases, would take place within a very small fraction of a second, a steady or static condition is reached, which might be indicated by electrostatic stress lines drawn from the wire to the ground, as illustrated in figure 3 by the fine dotted lines connecting the horizontal line to the ground surface below. If the wire be viewed on end (fig. 4), we must represent these stress lines

as extending out radially from the wire and bending over to meet a considerable portion of the ground surface below. As this arrangement is constituted, there is no energy transfer and the condition is static only. If now the far end of the line is earthed, as through an instrument or device which uses energy, as in figure 5, at the moment of such connection there would be a lowering of the intensity of the stress toward the receiving instrument and the line would be discharged were it not for the maintaining action of the battery, which still keeps up the difference of potential between line and ground. If the line is without resistance, this potential will have the same value all along the line, especially if the line is of uniform section and of uniform distance from the ground. The moment, however, the instrument at "I" takes energy from the line a current is found in the wire and a return in earth, and there is, so to speak, a flow of

Fig. 7.

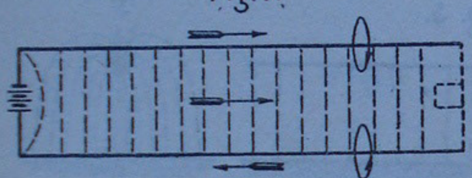


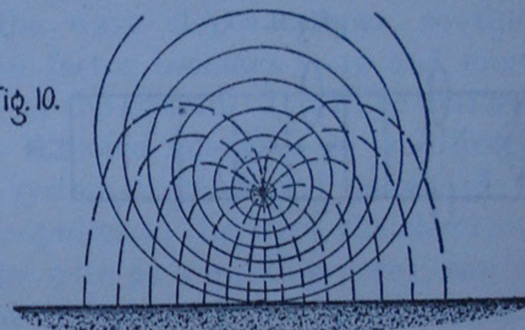
Fig. 8.

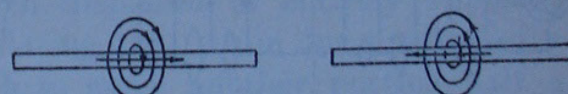
Fig. 9.

energy in the space between the wire and earth and in the ether surrounding the wire, in the direction of the arrow—that is, from the generating end to the receiving end. Surrounding the wire at this time there will be a magnetic field, which may be represented by whorls or lines of magnetism, so called, wrapped around the wire like so many hoops of all sizes (fig. 6), expanding in size away from the wire in all directions; and a similar magnetic effect, of course, is also produced by the return current in the earth. But on account of the conditions of conduction in earth being very devious and irregular, it would be difficult to map the magnetism generated. The system of magnetic whorls so developed on the flow of the current in the system reaches, for any definite current, a definite density after a short interval. In other words, the density of the magnetic field between the wire and the earth increases only up to a certain point. If the current, however, be doubled in any way, that field is doubled in density or there are twice as many lines packed in the space around the wire. If now we took instead of an earth-connected circuit one in which there are two wires extending from the generating battery or generator, the conditions will be the same except that the stress lines will now radiate from each wire and connect the wires by lines directly between them and by other curved lines outside. Such lines, or otherwise conceived "tubes of force," represent the static field or

the density and directions of electrostatic stresses in the electrostatic field where one wire will be positive while the other is negative. If, as before, the ends of the wire are free or open-circuited, no energy is transmitted, and the mere static stress exists. If, however, the wires are connected through an instrument receiving energy or utilizing the energy, then the magnetic system is developed, surrounding each wire and passing between the wires, and on the establishment of any given current these lines accumulate at a rapid rate until, in a small fraction of a second usually, a limit is reached. The magnetic field may then be said to be fully developed. Outside of the pair of wires the magnetic disturbance extends to very great distances, but is necessarily weak far away. The magnetic whorls in this case do not center themselves in circular paths around the wires and at equal distances therefrom, but between the wires they are more condensed or pushed toward the wires themselves—crowded, so to speak—while outside of the wires they expand (figs. 8 and 9). It must be remembered that these lines of force are merely symbols for what may be likened to a magnetic atmosphere. They indicate the density and direction of certain actions in the ether, called magnetic. It will be important to note, both in wire and wireless transmission, that the energy is transferred in the surrounding medium. The wire in ordinary wire transmission is, in fact, a sort of guiding center or core around which this ether disturbance carrying the energy exists. The wire may be bent or coiled, expanded or contracted without altering the essential nature of the process. So far, then, ordinary wire transmission is really a case of wireless transmission, with the wire for a guiding core for the energy (fig. 10).

Fig. 10.





It would take us too far to attempt to explain or theorize on the modern view of the passage of electrons in the wire forming the current, and the field they carry with and about them in giving rise to the stresses in the ether surrounding them. Suffice it to say that a moving electron must not only be accompanied or surrounded by the static stress field which it produces in the ether but also by a magnetic effect representing the energy of motion possessed by it. When a current which has been started in a circuit reaches a definite value it may be said to have reached a steady state. It would then

be a continuous current of constant value. Energy can be steadily extracted from such a system only by introducing some apparatus connected with the wire which is the guiding core for this energy.

Let us now consider the case of current of a different character, a fluctuating—or better, an alternating current. Let us substitute for the battery an alternating current generator, and assume a single wire with an earth or wire return, as in figures 3 and 5. Here the wire merely becomes positive and negative alternately, for the circuit is incomplete or unconnected as a circuit, and the stress lines from wire to earth or to other wires reverse periodically their direction plus to minus and minus to plus. This is true, of course, whether the earth be replaced by a second wire or whether three or more wires be involved, as in a three-phase alternating current circuit. By connecting any two of the wires through an energy-receiving apparatus R (fig. 11), the same action that takes place with the continuous current may be reproduced except that the energy now comes in waves and is not a continuous flow. In ordinary cases there are 60 complete waves or complete changes from plus to minus and back to plus in each second, and the system is then called one of 60-cycle frequency. A further important difference is to be noted between the alternating-current condition and the continuous. The action in the ether around and between the wires is now in the form of waves, both magnetic and electrostatic. Between wires there is an increase of electrostatic stress to a maximum, a diminution to zero, a reversal, etc. The magnetic field also rises, falls, reverses, and so on synchronously. The condition is no longer static, the medium around the wires is in a dynamic state and it is now possible to abstract energy steadily from it without actually diverting current from the line. We can, in fact, by such a system produce in neighboring conductors similar disturbances or currents, and along with these disturbances we may deliver energy.

Fig. 11.

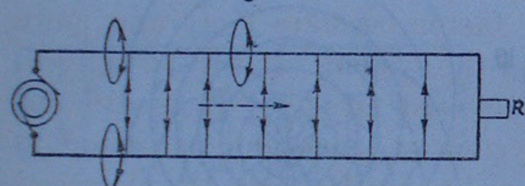
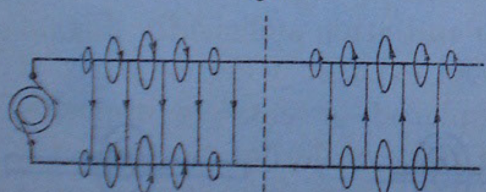


Fig 12.



The alternating-current transformer is then merely a device for bringing two or more circuits together as near as possible and enhancing the magnetic values which would normally exist around such circuits by the addition of an iron atmosphere, the iron core, so that the greatest possible transfer of energy from one (the pri-

mary circuit) to the other (the secondary circuit) may be accomplished. But in the wire itself, which leads from an alternating-current source, since there is an action called a current which changes, pulsates, or alternates, we have also around the wire core waves in the ether which, in fact, spread to very great distances; some small portion of the energy of each impulse not returning to the system, but passing outward into space as radiated energy.

This radiation may be a very small amount per cycle, especially where the outgoing and return wires are near together and parallel, and with low frequencies, such as 60 cycles, on account of the low number of waves per second and the low speed or rate of change in the fields surrounding the wire, the amount of energy carried off by free radiation into space is indeed negligible. But if we raise the frequency we raise the amount of energy which can be radiated proportionately to the number of waves per second, and we also make the rate of change higher and the wave slopes steeper, so that as the frequency rises the radiation factor becomes more and more important in dissipating the energy of the system. It will be noticed, however, that such energy is not directed energy. It is diffused through space around the electric system at work and passes off to illimitable distances. Since these impulses in the wire, the electrical waves sent along the wire (with the wire as a guiding core), can at the maximum move with the speed of light—186,000 miles per second—it follows that if the line is sufficiently long or the transmission sufficiently extended or the path of radiation sufficiently distant the wave stresses or fields or currents can exist at different parts of the system in phases either much displaced or entirely opposite. This may be rendered clear by stating that while one portion of a very long line might be positive to earth another portion half a wave length distant from the first along the same line would be negative to earth (fig. 12). In other words, there may exist upon the system at the same instant a succession of waves in opposite phase. Just as in vibrating strings in musical instruments or vibrating columns of air in organ pipes there are stationary waves, nodes, and internodes, so in electrical systems in vibration there can be nodes and internodes if the conditions are selected for obtaining that effect. Here the dotted vertical line indicates the nodes of the waves. We may thus have so-called stationary electric waves (fig. 12).

We find that on raising the frequency of an alternating-current system from, say, 60 cycles, the ordinary frequency, to 600 cycles, an effect which at first was hardly detectable now becomes important. It is the so-called "skin effect" whereby the current in a wire circuit tends to concentrate itself on the outer skin of the conducting wire, neglecting the inner copper, so that the inner core of the wire

might be left out. Consider the frequency still further raised, say, to 6,000 cycles, this "skin effect" of the conductor still further increases until the copper in the interior of a circular wire of a considerable size is now quite useless, and to get the advantage of such copper we must, as it were, take it out or spread it in a number of parallel wires spaced apart, or make the metal of the conductor in the form of a long sheet or in the shape of a thin tube or a cage of wires (fig. 13). This, in electrical terms, improves the conductivity and reduces the opposition due to self-induction; the inductance counter E M F. Let now the frequency be still further increased to tens of thousands or hundreds of thousands of cycles per second; then our conductor must necessarily become a still thinner or a still more extended sheet.

Fig. 13.

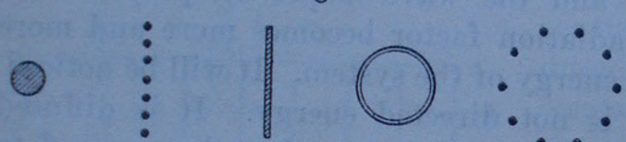


Fig. 14.

Fig. 15.

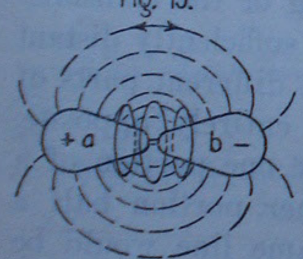
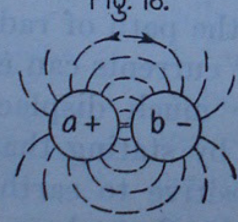


Fig. 16.



At the same time, if there are considerable differences of potential between the conductors thus arranged, the radiation factor may at last become very important, so that if the parts of the circuit are far apart, free radiation into space may dispose of a large fraction of the energy sent out. In the Hertzian oscillator, deducting that lost in the spark gap, practically the whole of the remaining energy supplied is radiated into space. The wave frequency may be very many millions per second, and the waves produced are in the nature of coarse light and heat waves. Figure 14 exemplifies diagrammatically the fact that with very high frequency waves a conductor carrying such waves will have surrounding it, if the space is unrestricted, magnetic systems of lines reversed in direction with nodes between, the distance apart of these waves or nodes being determined by the frequency in relation to the velocity of light, each complete wave outside the wire occupying a length equal to the velocity of light, 186,000 miles per second, divided by the wave length or frequency.

Figures 15 and 16 represent forms of Hertzian oscillator, consisting of plates or spheres *a b* of metal, separated by a small spark gap and charged in any suitable way, plus and minus with respect to each other, and allowed to discharge across the gap. The charges are then interchanged between *a* and *b* at a very high rate,

though the waves decay rapidly, and the system vibrates only for a short time or until the energy of the charge is dissipated in ether waves of exceeding high pitch into the surrounding medium. Were there no energy lost in the gap itself for forming the spark, and if the metal were a perfect conductor, the full amount of energy represented by any initial charge would be dissipated in the ether in these ether waves. Marconi, however, in his development of wireless telegraphy did not use the complete Hertzian oscillator. In setting up his transmitting antenna he took substantially half an oscillator, the other half being, so to speak, a phantom—the reflected image of the first half, as it were, in the surface of the earth, generally the sea surface. It would be represented by taking an extended copper sheet or surface coated with a fairly good conductor to represent the earth's surface and mounting above it, but insulated from it, a metal body, such as a vertical rod, which could be charged and which could discharge to the sheet through a small air gap. In this arrangement not only would waves be sent out into the surrounding ether space, but there would be current traversing the sheet as waves of current around the spot where the discharge of the insulated body took place. In fact, I think it would be possible to represent experimentally a modern wireless system with a diminutive antenna to represent the transmitting station, and extended copper sheet to represent the earth's surface, and with investigating or receiving antennæ set up here and there or moved from point to point on the extended surface.

Fig. 17.

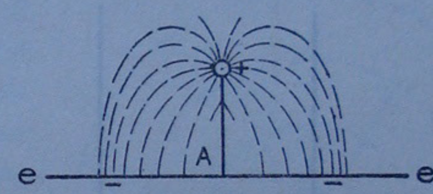
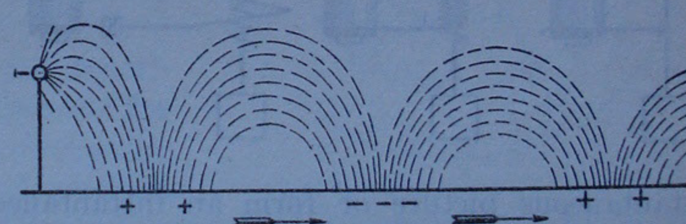


Fig. 21 A.



Here, although the disturbance and the energy conveyance is in the ether around the antenna (or the part representing the half of the Hertzian oscillator), the energy is guided in its direction by the current in the sheet representing the surface of the sea, just as in the wire transmission the energy is guided by the wire as a core. On account of the enormous extent of the earth's sea surface, there is no need of a return circuit. The energy sent out moves in all directions, guided by the conducting water surface or land surface, as the case may be. There will necessarily be a rapid attenuation

of the energy as it leaves the sending or transmitting antenna and spreads out to fill a wider and wider space around it. The higher the sending antenna the greater the distance which can be reached before the attenuation is too great for imparting signals.

Let us consider for a moment by the aid of a figure the actions which must occur in wireless transmission on the sending out of energy from the transmitting antenna. Referring to figure 17, we will represent by *e—e* the surface of the earth as if it were flat, and for moderate distances this will be substantially the case. We will erect on that surface a tall mast A of conducting wire or wires which, at the top, shall have an extension to increase its capacity. This might be a large ball of sheet metal. Usually, for construction to be practicable, it is a set of wires—a sort of cage or a skeleton body. Now, by any system, inductively, conductively, or otherwise, or by what is known as close or loose inductive coupling or what not (figs. 18, 19, 20) we cause electric disturbances, such that at one instant the top of the antenna becomes positive and at the next instant negative, many thousands—even hundreds of thousands—of times per second. In other words, we impress a high-frequency wave upon this vertical mast. We will try to present an instantaneous picture or form an instantaneous image of what the condition is at the beginning of the process.

Fig. 18.

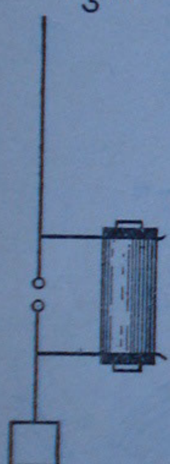


Fig. 19.

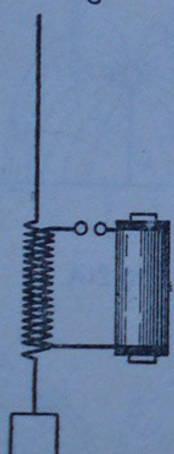
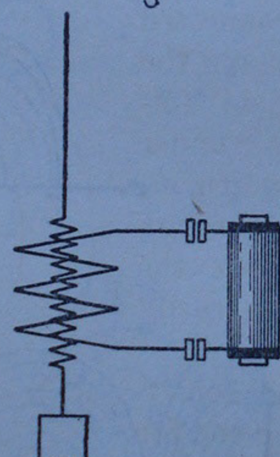


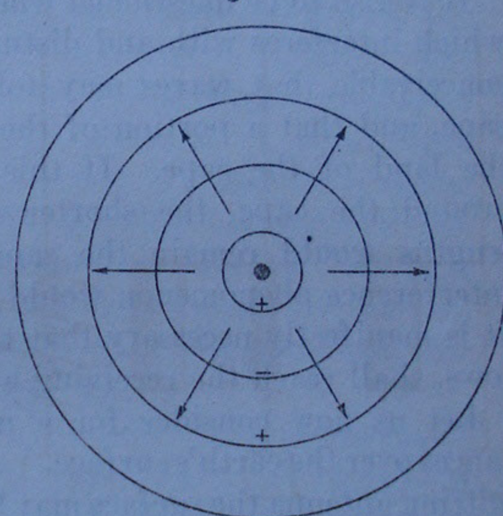
Fig. 20.



Let us suppose that the charge is positive at the top, and necessarily the surface below and surrounding the mast will be negative. Electrostatic lines will extend from the mast, and particularly from the expansion at the top down to the earth's surface in all directions around the antenna, as in the figure. The medium around the antenna will be stressed electrostatically. This would be all, provided the charges were stationary, but the system we are considering is dynamic. The plus charge is replaced by a minus charge at the top, and a current of a high frequency runs up and down the antenna, but so also does this current extend into the sea radially from the foot of the antenna, replacing the negatively charged area by a positively charged zone, as it were, while the top of the antenna is now negative where it was formerly positive. (Fig. 21 A (p. 251), one side only shown, and fig. 21 B, in plan.)

As this action goes on, however, the zone of charged surface widens, and ether waves are, so to speak, detached from the antenna, and electrostatic lines join now through the air or ether above the successive zones which surround the antenna as great circles or flat rings of the sea surface. A plus area is followed by a minus, a minus by a plus, etc., and to indicate the effect in the space above, we draw lines which follow these areas, extending up into the ether above the surface, but moving away from the antenna with the velocity of light. The moving charges in the sea surface represent radial currents which are in opposite phase at different portions of the sea surface, and spreading at 186,000 miles per second, and these currents necessarily generate magnetism or lines of magnetic force in the medium directly above them. These lines extend around in zones with diminishing intensity upward from the sea surface as the distance from the surface increases. Even within the water itself a similar action, but more restricted, takes place. The charges in the water are connected by electrostatic stress lines, and the compensating magnetic field follows the current, but this "under water" effect does not concern us, as what we work with is the energy conveyed in the space above the sea, the other not being so easily recoverable.

Fig. 21 B.



The system as thus far constituted is merely an arrangement for delivering energy in high-frequency waves to the widespread medium around the antenna. There is no selective action whereby it is focused anywhere—it is as a "voice crying in the wilderness." It can be picked up or recognized in any direction by anyone who is within range. If, now, we are to receive signals such as are made by interrupting or disturbing at intervals this system of radiation of energy, as in ordinary telegraphy, we must set up somewhere a receiving apparatus which will enable us to pick up whatever small fraction of the energy reaches it and, if possible, a sufficient fraction of such energy for the recognition of the signals. If the signal can be recognized—no matter how small the fraction of the energy sent out is which we collect at the receiving station—the system succeeds. There is no question of efficient transmission, as there is in the ordinary power-transmission systems. The latter are for the transmission of energy with as little loss as possible, the former for the transmission of signals only.

In the antenna transmission just considered it is assumed that the surface of the earth is, generally speaking, a good electric conductor. The surface of the sea is sufficiently good. Dry land surface, however, is not a good conducting sheet, and even though moist it is generally so irregularly conducting that obliteration of the waves and loss or absorption of the energy must necessarily occur. Obstacles, such as dry rock ranges, may absolutely prevent the waves from passing over them. It must be borne in mind that these waves have no inertia, as such, and that the energy must be guided to its destination by a conducting sheet. This calls to mind the efforts that were made to connect Lynn and Schenectady by a wireless system, but without success. Occasionally signals were received, but in general they were too indistinct to be recognized. It is more than probable that the dry rock ranges of the Berkshires in western Massachusetts were sufficient of an obstacle to prevent the energy of the waves getting across them.

It is also to be questioned whether there may not be another action which interferes with and disturbs the integrity of the waves. It is conceivable that waves may follow a water surface, even around a cape, and that a portion of the energy may take a short cut across the land of the cape. If this be so, the longer course would be around the cape, the shorter course across the land. The wave lengths would remain the same, and an out-of-phase relation or interference phenomenon would take place to a greater or less extent. It is manifestly necessary that the energy, by whatever course it follows, shall reach the receiving apparatus in phase.

Let us now consider for a moment the conditions at great distances over the earth's surface. At moderate distances from the transmitting antenna the surface may be considered as flat. The conducting sheet guiding the energy is flat or plane, but at great distances the curvature of the earth's surface becomes an important factor. For a time there was a great deal of discussion as to the reason why the energy in the wireless transmission seemed actually to follow the curvature of the earth, instead of going straight away, as in the case of Hertzian or heat and light waves. If the waves had been generated by a large Hertzian oscillator, it would not be possible for them to so follow the earth's curvature, but inasmuch as they are in wireless work produced and, as it were, positioned upon a conducting sheet (the sea surface), then it follows that the energy must be guided by that conducting sheet or surface, regardless of its extent or its curvature. I have never been able to understand why so much discussion has been needed to clear up this point. Wireless waves have no inertia—they follow the course of the charges which produce the stress and of the magnetic field, due to these charges in motion. These charges in motion are the currents in the conducting sheet, which may or

may not be curved. In the curved surface of the ocean the zones of charge continually expanding, plus and minus, respectively, are still connected by the electrostatic lines above them, and the moving charges still generate the same magnetic field as they traverse radially or outwardly in the curved instead of the plane sheet (fig. 22), and this curved conductor still guides the energy, just as the wire does in ordinary transmission. It would seem, if this is the correct view, that at a distance comparable with that of a quadrant of the earth's circumference the form of the wave would be such as to cause the stress lines to lean backward with respect to the surface, tending to keep their original relation to the transmitting antenna as they were detached therefrom (fig. 22, at L). This assumes that the velocity of transmission is the same as that of the speed of light, both for the currents in the sea and for the stresses above it.

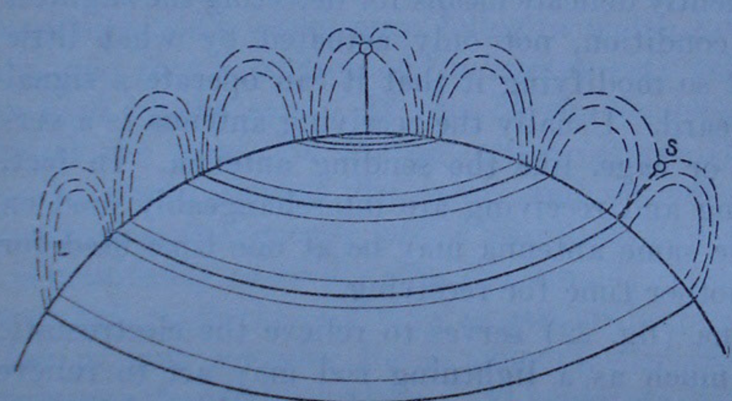
Marconi's success as a wireless pioneer depended largely upon the choice of a sufficiently sensitive receiver. Two elements are necessary in the receiver. First, a conducting structure which gathers up the energy from the medium, the ether, above the earth's surface. The other element is a sufficiently delicate means for detecting the slightest changes of electrical condition, not only actuated by what little energy is received, but so modifying it that it can operate a signal which can be seen or heard. Usually the receiving antenna is a vertical conducting mast or cage, like the sending antenna. In fact, the functions of sending and receiving are interchangeably used on the same structure; the same antenna may be at one time used for transmitting and at another time for receiving.

The receiving antenna (fig. 22) serves to relieve the electrostatic stress in its vicinity, much as a lightning rod may act to relieve cloud to earth stresses. If its direction could be made to follow or be parallel to the actual course of the transmitted lines in the space near it, it would be most effective, and if, further, it could extend sidewise over a considerable extent of the wave front, it would gather up more energy. These conditions, however, can at best be only approximately met. If the receiving antenna were of such a character as to have no oscillation rate of its own (a damped circuit) it would receive energy in a small amount from the transmitting antenna independent of the frequency, but as this would in most cases be far from sufficient, it is desirable to accumulate energy in the receiver from a train of waves at a definite rate. To do this the principle of syntony or tuning is brought in. Everyone is familiar with the two tuning forks, where one is sounded and the other is placed at a distance away. If the two forks are not in harmony, no effect of the one fork on the other follows, but if they are accurately tuned in unison, the sound of one fork at a considerable distance from the other starts the second in vibration and produces an audible sound

from it. The second fork is, in fact, a structure particularly well adapted to gather up the energy of the sound waves which reach it, receiving from each wave a small portion of energy and accumulating such energy until the fork itself is brought into palpable vibration. By applying this principle in wireless telegraphy—that is, by causing the rate of vibration or frequency of the electrical waves to be the same in the transmission and in the receiving antennæ systems, constructing both to possess a normal rate as if they were to be electrical tuning forks of the same pitch—the amplitude of the received impulses is so greatly increased that signal strength is reached where otherwise failure would have resulted. The one thing which has characterized the more recent advances in wireless telegraphy has been the accuracy of tuning and the removal of disturbing influences which would interfere with the tuning.

Formerly the transmitting circuit was excited by means which tended to disturb the actual normal rate. If excited inductively, the inducing or primary circuit had a rate of its own, which was apt to interfere with that of the vibrating antenna system. However, what is known as loose coupling (fig. 20), instead of close coupling (fig. 19), to the primary or exciting circuit causes such confusion of rates to be nearly negligible if, particularly in the exciting circuit, the current is well damped, as it is termed, or confined to a single brief impulse as far as possible. In such case the antenna circuit, in transmitting, acts as if it were a bell struck with a sudden quick blow, and it vibrates at its own rate without disturbance or interference. At the receiving end (and there may be, of course, many receivers in the space around the transmitting antenna), the "listening-in" process consists in adjusting the rate of vibration of the receiving circuit by variable condensers or inductances, so that the maximum loudness of the received signals is attained. The two systems, transmitting and receiving, are then in tune.

Fig. 22.



Accuracy of tuning is evidently very important if stations are to be simultaneously transmitting when near together, as only in that way can one station send out energy without interfering with the other; the particular receiver for which the signals are intended being tuned for the particular antenna sending these signals. In spite

of the accuracy of tuning, however, high-power stations may, in fact, cause high frequency waves of high potential in all surrounding wire or metal structures if near enough. Burn outs, or even fires, may occur from this cause. Hence it is desirable that high-power sending stations should be well removed from centers of population where there are electric circuits and electrical apparatus likely to be interfered with or injured.

It may be here pointed out that the limit of potential which is available in wireless transmission is the same as that of long distance transmission by wire and for the same cause. Naturally, if the potential on the sending antenna can be raised, the amount of energy which can be put into the wave impulses will be increased, but there comes a time when an increase of potential on the wires of the antenna gives rise to a corona loss—much as the increase of potential in wire transmission produces a corona loss. The conductors of the system, in such a case, are surrounded by a blue discharge which is even visible at night and which frequently can be heard. When this condition is reached every further increase of potential simply increases the corona loss without adding correspondingly to the energy transmission. Just as in wire transmission it can be avoided by increasing the diameter of the conductors, so in wireless work it could be avoided by constructing the antenna system of hollow tubes with smooth exteriors, and the imagination may be permitted to depict a sending tower of polished metal surmounted by a sphere of similar material and worked at millions of volts. No limit can be set to the amount of energy which might thus be radiated, and no limit as yet can be set to the distance around the earth to which signals might be sent by such means.

One curious fact which has been developed in the work of wireless signaling is that daylight, especially sunlight, is very detrimental to transmission as compared with the night. That is to say, if the wireless waves are to traverse the sea surface in sunshine, the chance of receiving them in sufficient force to produce signals at great distances is far less than when they are sent at night. It is probable that this difference is not due to any single cause—it may be the effect of a combination of causes. It is a notable fact, too, that this difference between the effectiveness of daylight transmission and night transmission is accentuated at the higher frequencies.

Though the cause is still somewhat obscure, we may venture a suggestion or hypothesis which may have a bearing on the case. Referring to figure 23, we have tried to show the condition. The electrostatic field at the water surface at the same instant is as in figure 21 produced in zones around the antenna *A*, spreading with approximately the speed of light. It is well known that under the

action of the violet and ultra-violet rays of light any surface, having a negative charge will leak its charge and ionize the air near it. This may occur in sunlight over such areas as are marked minus in the figures, and the several minus signs would mark or indicate air ionized and negatively electrified over the negatively charged zones. No action would be expected over the positive areas or zones. But the zones are not stationary; they are widening very rapidly, so that a positive zone or zones takes the place of negative so far as any location is concerned. This may be expressed by saying that the water surface which at one instant was negative and gave out negative ions under the influence of light would, in an exceedingly small fraction of a second and before those ions could get away from electric contact with such surface, become positive and the free ions would now return and neutralize a portion of the positive charge. Thus the negative zones or wave elements would lose part of their charge to ionize air, and the positive waves would be weakened by such negative leak neutralizing them in part. This action, however feeble at each wave, would be continuous over hundreds if not thousands of miles, and continuously damp out the widening system of waves. The effect would be less marked with low frequency waves, as there would be a proportionately less number of opportunities for this neutralization per second. Besides, with the lower frequency there is more time for the separation of the negative ions to such distance from the water surface that they do not combine with the positive charges; being, as it were, better insulated from them or diffused in the air stratum.

Fig. 23.

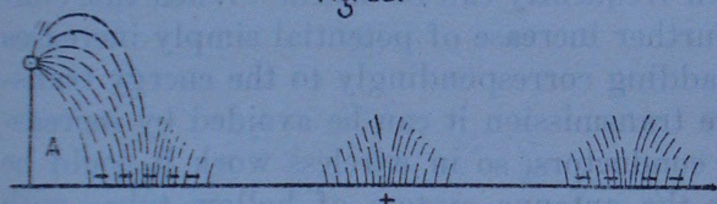
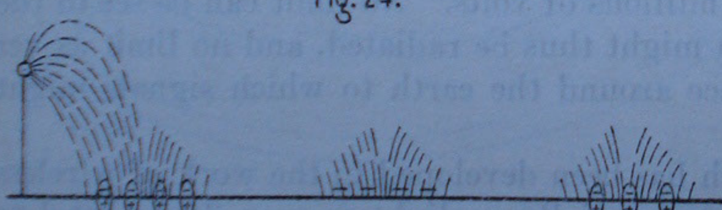


Fig. 24.



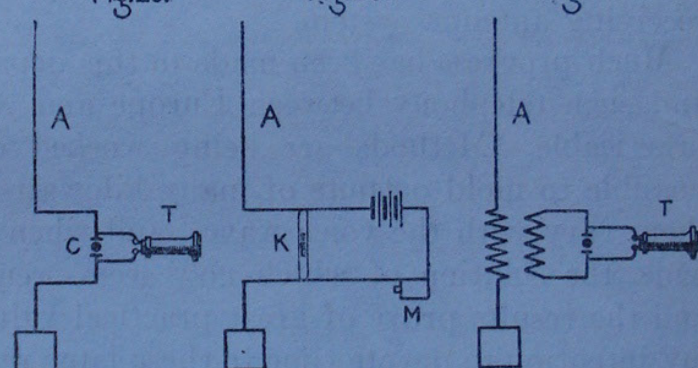
In figure 24 an attempt is made to picture this action of attenuation in the presence of light. The negative charges in the air layer, as in figure 23, have no positive charges under them, the encircling lines about the + and − signs indicating combination and neutralization.

When the wireless waves reach the receiving antenna, owing to attenuation from spreading or loss as above, they are very feeble. The

daylight effect, as pointed out by Fessenden, is much less with the lower frequencies, such as 100,000 per second as compared with 600,000 or 800,000 waves. Consequently there is not the same great difference in strength of signals between night and day work with such lower frequencies. Moreover, frequencies of 100,000 or even 200,000 are capable of being generated directly by high-speed high-frequency dynamos with the added advantage that the waves sent out are maintained at their full amplitude and are not, as with waves produced by spark discharges, subject to damping or decay from maximum to zero after a few oscillations.

Whatever the nature of the waves sent out, there is in all cases the need of an exceedingly sensitive apparatus for converting the slight electric effects upon the receiving antenna into signals. The original apparatus of Marconi included the Branly coherer, used by Lodge in Hertzian wave transmission as a detector. It is indicated in figure 26 at *K*, with its battery and sounder magnet *M*. The receiving antenna discharge in passing to earth broke down the insulation of the filings of the coherer, so that the local battery current could pass in the circuit, including a magnet *M* and so record the signal. The liquid barretter of Fessenden, the various forms of rectifying crystal detectors and magnetic detectors, have been extensively used. Our time does not permit a detailed description. Figure 25 indicates at *C* a crystal detector rectifying the impulses from antenna *A* so as to work a high-resistance telephone receiver *T*, to which the operator listens. Figure 27 shows the same apparatus, but connected inductively to the antenna circuit by a transformer.

Fig. 25. Fig. 26. Fig. 27.



reaching the telephone *T* was such as to produce a low note, the signals were easily drowned by extraneous noises or induced effects. He found that the human ear reached a maximum of sensitiveness at about 900 waves of sound per second, so that the signals were heard distinctly when otherwise they would have been missed. This is the meaning of the substitution of dynamos of about 500 cycles for exciting the wireless antenna in place of the ordinary machines of lower frequency.

The problem of wireless telephony has attracted attention for a number of years past. I well remember witnessing some of the

earlier work of Fessenden in this fascinating field, in which he was pioneer. The wireless telephone speech was free from all disturbing noises and interferences so common on ordinary telephone lines. Briefly, such telephony depends on the ability to control the voice waves and vary in accordance therewith the energy given out by the transmitting antenna and to do this with a fairly large output of energy.

By employing a method I described about 1892, it is possible to generate a continuous wave train by shunting a direct current arc with a capacity (condenser) in series with an inductance, the frequency rate depending on the electrical constants of these parts of the apparatus. This system, which was the subject of the United States patent taken out by me in the early nineties, has been variously called the Duddell singing arc, or later the Poulsen arc. Poulsen employed it with modifications in his system of wireless telephony. Long before this work of Poulsen, Fessenden had used a high-frequency dynamo for securing the continuous train needed. A suitable microphone transmitter was made to so alter the relations of the waves in transmitting and receiving antennæ, that voice waves could be received in an ordinary telephone connected with the receiving antenna system.

Much progress has been made in this department of wireless work, and such telephony between Europe and America may yet become practicable. Methods are being worked out whereby it may be possible to mold outputs of many kilowatts of energy so as to have them vary with the voice waves, and when this is done many problems, the solution of which now seems remote, may become solved and the results prove of great practical value. It was not, however, my intention to devote time to these later researches, but to endeavor to present to the mind's eye a view of the nature of wireless transmission which should show the similarities to ordinary transmission by wire and also the differences. Furthermore, I hope I have shown it to be evident that future transmission of energy at high efficiencies will still demand the wire core for guiding that energy to its destination.

YONKERS, NOV. 29, 1881.

"*John W. Keely, Esq., Dear Sir:*

I have lately heard that you continue to pursue your old policy towards the Directors and Stockholders.

I much regret this on your account as much as on account of the stockholders & on account of the loss to the world for a time at least, of what I believe to be your really valuable invention.

I do not in any way interfere with the committee of the Board of Directors, & for anything that I know they may already have commenced suit against you. I have prepared this letter without the knowledge of any officer or stockholders.

My particular reason for writing is to give you a warning, & it is this; if you allow a suit to be begun & continued I predict the following result to yourself.

First. You will become a pauper.

Second. The whole community will put you down as either a fool or a fraud, for every body will see that you are killing yourself, & some will think that you have not your right mind, & others that you are a rascal who in trying to defraud others ruined yourself.

Third. The men who have such influence over you, who eat, drink & sleep with you will desert you, & if you have any friends left they will be the very men whom you have opposed and injured.

Fourth. Instead of your name being handed down to posterity as worthy of respect & remembrance for persistent & successful labor, & for a great invention, you will at the best be spoken of as a genius, but as so deficient in integrity as to be considered rather a warning than an example.

Very truly yours,

JNO. C. HAVEMEYER.

P. S. Since writing the above, I learn that the papers are all prepared & that legal proceedings will be begun against you on Saturday or Monday at the latest. I am informed that the complaint against you is expressed in very strong language, and that its publication will place you in a very unenviable position.

I sincerely trust that you will be wise enough immediately to change your course, & thus prevent the service of the papers upon which I learn the committee are fully determined.

J. C. H."

The minutes of the Company having been sent to New York, I have not been able to see them for a month, and consequently cannot give some details I had intended.

J. H. L.